# IGBT를 이용한 인도 철도시스템
## Indian Railway Locomotives with IGBT Based Traction Control Converter

데버랜전고팔* 노영환** 김윤호***
Devarajan Gopal Lho, Young Hwan Kim, Yoon Ho

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### ABSTRACT

Standard Gate Turn Off (GTO) Thyristor drive technology results in inhomogeneous turn-on and turn-off transients which in turn needs costly dv/dt and di/dt snubber circuits. Added to this GTO is bulky in size, needs external cooling, slower switching time etc. The development of high voltage Insulated Gate Bipolar Transistor (IGBT) have given new device advantage in the areas where they compete with conventional GTO technology.

Indian Railway has developed first IGBT based traction converter and was commissioned in November 2006. Some of the supremacy of IGBT are smaller in size, no external cooling is required, built in power supply which enhances reliability, lower switching losses which leads to higher efficiency, reduced gate drive, high frequency operation in real time etc. These advantages are highlighted along with IGBT Traction system in operation.

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### 1. Introduction

Indian Railway started their first Dieselization program by setting up of **Diesel Locomotive Works (DLW)** in 1961 and produced first Diesel locomotive in 1964 with DC-DC traction system. In 1994 it produced first locomotive with AC-DC Technology which was maintenance free and more efficient as compared to DC-DCt echnology. Indian Railways signed a Technology Transfer Contract with Electromotive Division (EMD) of General Motors USA in 1995. With this technology, DLW started manufacturing locomotives with AC-AC traction system.

EMD technology employs a three phase transmission system. In this system, rectified DC output of the main alternator is fed to Traction Controller Converter (TCC), which in turn inverts DC to controlled AC output and supplied to traction motors for locomotion.

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* 우송대학교 교수, 철도전기 · 정보통신학부 (Railraod Electrical Engg. Woosong Univ.)
** 정회원, 우송대학교 교수, 철도전기 · 정보통신학부
E-mail: yhlho@wsu.ac.kr Tel.: (042) 629-6731, Fax.: (042) 629-6629
*** 정회원, 중앙대학교 교수

The inverters presently employed are Siemens make Voltage Source PWM inverters with Gate Turn Off (GTO) Thyristor Standard GTO drive technology results in inhomogeneous turn on and turn off transients. The disadvantages of GTO are bulky in size, needs excessive cooling, slower switching time etc. The development of high voltage IGBT (Insulated Gate Bipolar Transistor) have given new device advantages in areas where they compete with conventional GTO technology. Therefore, GTOs are fast phasing out from the most of the power applications. In traction field as well, world over GTOs are being replaced by IGBT in traction converters. The first IGBT based traction converter is complete and the first locomotive with this traction converter is turned out on 4, November 2006.

## 2. Power Converters for Traction Applications

Traction converters are fed by DC mains (3KV) or Single phase AC lines (25 KV, 50 Hz) in electric trains. High voltages IGBTs are currently replacing GTOs in high power traction applications. Devices in the voltage classes 3 KV, 4.5 KV, and 6.5 KV are available from several manufactures.4.5 KV and 6.5 KV. IGBT have the same thermal conductivity and hence the same dissipation. Today, 6.5 KV IGBT has combined the PT (Punch Through) and NPT (Non Punch Through) features.

### 2.1 Multi-system IGBT converter

A multi-system IGBT converter with input chopper is shown in Fig. 1. In the AC mode, the DC link of the four quadrant converter and the synchronous motor side inverter are connected. In DC mode the DC links are separated. The DC link of the four quadrant converter is directly connected to the line. Its IGBT together with an additional choke are used as step down converter, which feeds the DC link for the motor side. The input to the chopper is directly connected to the line, 6.5 KV IGBT is being used. It may be noted that this configuration uses only one four quadrant converter as input chopper.

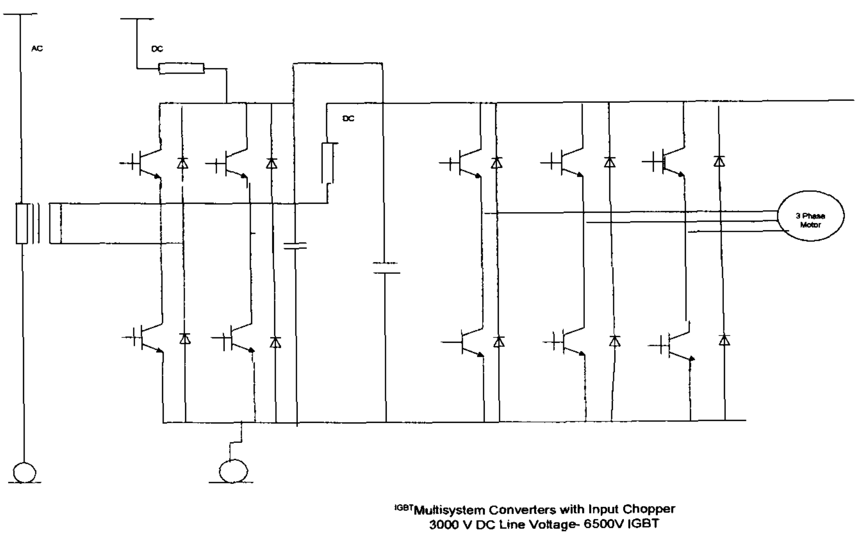


Fig.1 Multi-system Converters with Input Chopper

## 3. General considerations for IGBT Power module

In high power systems rapid turn on and turn off operations produce harsh dynamic conditions. The power circuit, snubbers, and gate drive must be designed to deal with extreme di/dt and dv/dt stresses. High transient voltage is likely to occur if leakage inductance in the power circuit and snubbers is not minimized. Ground loops will cause noise problems. Here mechanical and component layout plays an important role for reliable and efficient operations.

### 3.1 Turn off Surge Voltage

Turn off surge voltage is the transient voltage that occurs when the current through the IGBT is interrupted at turn off. For this purpose a parasitic inductance L (lump inductance) is added in the bridge circuit. When the device turns off a voltage equal to $L\frac{di}{dt}$ appears across the inductance in opposition to increasing current in the bus. Sufficient care should be taken to avoid commutation failure.

### 3.2 IGBT Gate Drive

IGBT require gate voltage to establish collector to emitter conduction. The parameters to be considered are (i) a drive circuit includes a device off biasing off biasing, gate charge, ruggedness requirements and power supply availability. A recommended drive circuit must include substantial on biasing and off biasing. Normally turn on gate voltage is about $15\ V \pm 10\%$ is recommended to minimize the on state loss. An IGBT will be turned off when the gate voltage is zero. In order to ensure that IGBT stays in off state even when dv/dt noise present, an off bias must be used.

### 3.3 Gate Drive Layout

Gate drive layout is critical to avoid possible oscillations, slow rise of gate voltage, loss of noise immunity, sag in supply voltage or reduction in efficiency of the gate protection circuitry.

General lay out guidance are:

(i) The layout must minimize the parasitic inductance between the driver's output stage and IGBT. That means, one need to keep the loop are as small as possible.

(ii) Care must be taken to avoid coupling of noise between the power circuit and the control circuit. Shielding the gate drive must be considered carefully. This will in turn reduce the ground noise level.

(iii) Use twisted pair wire, if direct connection between the drive circuit and IGBT is not possible.

(iv) Use shielded PCB lines while routing the potential lines (dv/dt) to reduce the coupling noise.

(v) Parasitic capacitance between high side of gate drive and low side gate drive. Necessary measures need to be taken to reduce parasitic capacitance. Opto-couplers may be used here with proper care.

### 3.4 Free Wheel diode Recovery surge voltage

Free wheel diode serves two main functions in controlled rectifier. (i) It prevents the output voltage from becoming negative. (ii) The load current is transferred from the main controlled rectifiers to the free wheeling diode thereby allowing all of its IGBTs to regain their blocking states. The advantages derived from free wheel diodes are (a) improved power factor and (b) improved load current waveform and thereby better load performance.

### 3.5 IGBT Selection

The important points are to be noted for IGBT selection. The first criterion is that the peak collector current during operation including any required overload current must be less than $2\times I_{rated}$. The second criterion is that the IGBT operating junction temperature must always be kept below $T_{j(\max)}$ (about $150^{o}C$ in normal operation including expected motor overload. The other point stobe considered are power dissipation and thermal considerations. A good estimation of total power losse shave to be accounted (Conduction losses and Switching losses).

Conduction losses are the losses that occur while the IGBT in on and conducting current. The total power dissipation during conduction in computed by multiplying the on state saturation voltage by the on state current. In PWM this has to be multiplied by duty cycle. Switching loss is the power dissipated during the turn on and turn off switching transitions. In high frequency PWM losses can be substantial and must be considered in thermal design. The average switching power loss is computed using the equation

$$P_{SW} = f_{SW} x E_{SW(on)} + E_{SW(off)}$$

where

$f_{SW}$ is Switching Frequency

$E_{SW(on)}$ is turn on switching energy, and

$E_{SW(off)}$ is turn off switching energy

The main use of the estimated loss calculation is to provide a starting point for preliminary device selection. The final selection must be based on rigorous power and temperature rise calculations.

### 3.6 Snubber Design

Snubber consists of a series combination of a resistor and capacitor in parallel with IGBTs, It is mainly used for dv/dt protection. Snubber circuits are usually used to **control turn off** and **free wheel diode recovery** surge voltages. In some applications snubber circuits are used to reduce switching losses in the power devices. General recommendations for **snubbers are not possible** to make because the type of snubber needed and the component values required are highly dependent on the power circuit layout. In addition factors such as cost and operating frequency must be considered while selecting the snubber for a particular application.

#### 3.6.1 Snubber types

There are four different types of IGBT snubber circuits. For low power IGBT, a simple low inductance film capacitor C may be connected on a dual IGBT module as shown in Fig. 2(a). This snubber is able to provide a low cost control of transient voltages. However as the power levels increase, snubber Fig. 2(a) may begin to ring with parasitic bus inductance. Snubber Fig. 2(b) solves this problem by using a fast recovery diode to catch the transient voltage and blocks possible oscillations. The RC time constant ($\tau$)of the snubber should be approximately equal to one third of the switching period ($\tau \approx \frac{T}{3} \approx \frac{1}{3f}$).

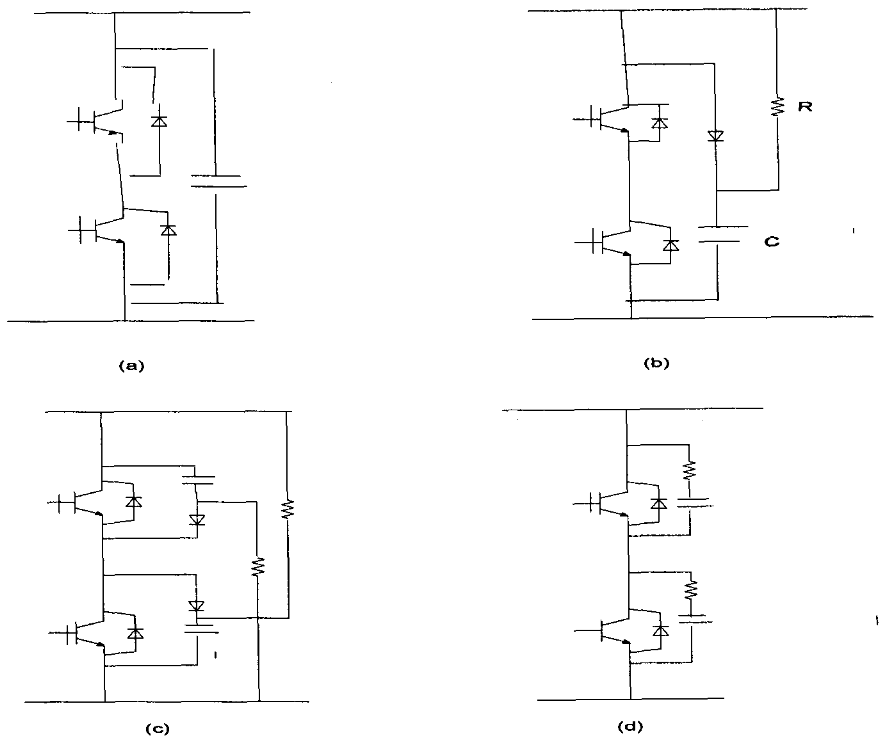


**Fig. 2 Different Types of Snubbers**

For IGBTs operating at high power levels, the parasitic loop inductance of this snubber become too high and in turn effectively control the transient voltages. For high current applications, snubber circuit given in Fig. 2(c) is normally used. This circuit functions similar to Fig. 2(b) and the only difference is it has lower loop inductance because it is connected directly to the collector to emitter of each IGBT. The snubber given in Fig. 2(d) is useful for controlling transient voltages, parasitic oscillations, and dv/dt noise. Here the losses are quite high and it it is normally not suitable for high frequency applications. In **very high power IGBT circuits,** it is helpful to use a small snubber given in **Fig. 2(d) inc on junction with a main snubber given in Fig. 2(c) in order to help control parasitic oscillations** in the main snubber loop. For very high power applications, it may be advisable to combine **Fig. 2(a) and (c) to reduce the stresses on the snubber diode.**

### 3.7 Short Circuit Protection

If a short circuit occurs the stress on the IGBT must remain within the Short Circuit Safe Operating Area (SCSOA).Common methods of sensing the short circuit are current sensing and de-saturation detection. Once a short circuit is detected, several technique can be employed to protect the IGBT from destruction. The most common technique is simply turn off the IGBT with in 10 msec. But, in this case, the snubber must be designed for the short circuit condition. However, it is recommended to use turn off techniques that control the $V_{GE}$ in order to reduce the stress on the IGBT.

### 3.8 Handling Precautions

IGBT gates are insulated from any other conducting region, care should be taken to prevent static build up which could possible damage the gate oxides. Never touch the gate terminals during assembly and keep the conducting foam in place until permanent connections are made to the gate and emitter control terminals. Try to ground parts that are coming in contact with gate terminals during installation.

Multi-system IGBT converter designed for Indian Railway is meeting the following needs. They are shown in the graph (i) Tractive Effort vs Speed Characteristic (ii) Speed vs Alternator Output Current & DC Link Voltage Characteristics, and (iii) Dynamic Braking Characteristics. These graphs are given in Fig.3 to 5 respectively.

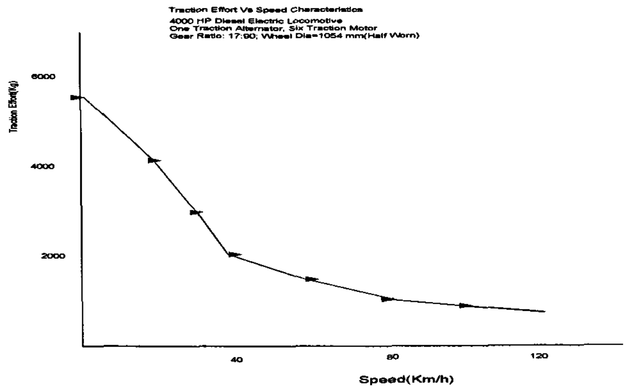


**Fig. 3** Tractive Effort Vs Speed Characteristic

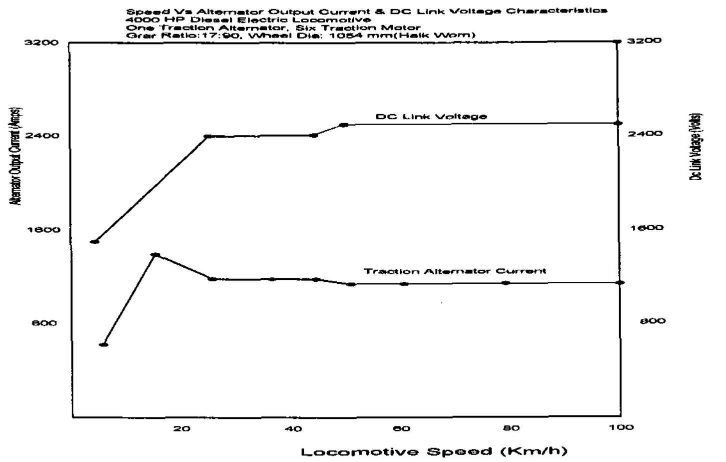


**Fig. 4** Speed vs Alternator Output Current & DC Link Voltage Characteristics

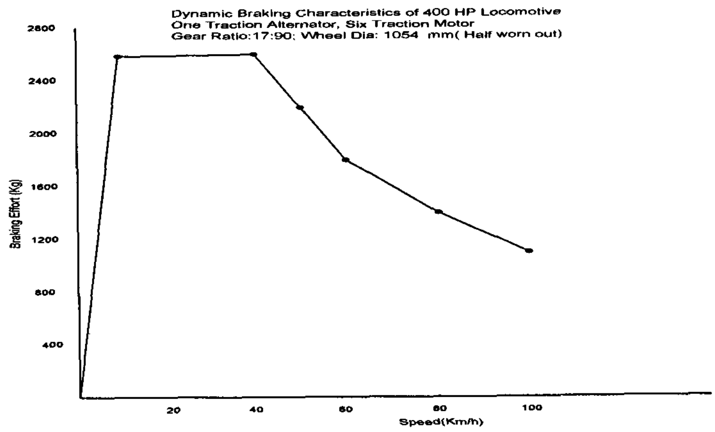


**Fig. 5** Dynamic Braking Characteristics

## 4. Technical Superiority

IGBT are technically much superior as compared to GTO and are listed as:

(i) IGBT is much smaller in size compared to GTOs. (ii) It does not require external cooling. (iii) It has a built in power supply and hence eliminates separate power supply required for GTOs. This enhances the reliability. (iv) IGBT switching losses is lower which leads to higher transmission efficiency. (v) Reduced on state and turn off losses through minimization of the silicon thickness. (vi) IGBT gate drive requirements are less especially during conduction. (vii) High frequency operation for continuous and dynamic conditions (viii) faster response time due to transistor based technology. (ix) Smaller size generates space in the converter cubicle to house hotel module.

## 5. Conclusions

The development of traction converters features on simplicity, reliability and efficiency. IGBT employs simple snubbers and the inverter is simplified to some extent, with the development of high voltage (6500V) IGBT. The development of high voltage IGBT have given new device advantages in areas where they compete with conventional GTO technology. Therefore, GTOs are fast phasing out from the most of the power applications.

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